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Experimental Studies on the Thermal Performance of a Parabolic Dish Solar Receiver with the Heat Transfer Fluids SiC + Water Nano Fluid and Water

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An experimental investigation has been carried out with aa point focusing dish reflector of 12 square meters aperture area, exposed to the average direct normal irradiations of 810 W/m^2. This work focuses on enhancinge the energy and exergy efficiencies of the cavity receiver by minimizing the temperature difference between the wall and heat transfer fluids. Two heat transfer fluids Water and SiC + water nano fluid have been prepared from 50 nm particle size and 1% of volume fraction, and experimented separately for the flow rates of 0.2 lpm to 0.6 lpm with an interval of 0.1 lpm. The enhanced thermal conductivity of nano fluid is 0.800115 W/mK with the k_{eff}/k_b ratio of 1.1759 determined by using the Koo and Kleinstreuer correlation. The maximum attained energy and exergy efficiencies are 29.14% and 24.82% for water, and 32.91% and 39.83% for SiC+water nano fluid. The nano fluid exhibits enhanced energy and exergy efficiency of 12.94% and 60.48% than that of water at the flow rate of 0.5 lpm. The result shows that the system with SiC+Water produces higher exergy efficiency as compared to energy efficiency; in the case of water alone, the energy efficiency is higher than exergy efficiency.

Keywords: Direct Normal Irradiation, cavity receiver, heat transfer fluids, nano fluid, exergy factor

Introduction

The concentrated solar power generation and its applications are in center of attraction for the researchers, which need more research and development efforts in materials and technologies, towards achieving the maximum possible energy and exergy efficiencies. Compare with trough and tower collectors based on technological viewpoint, the parabolic dish collector occupies less area and suits for small and medium scale applications with high temperature output. David Barlev et al. [1] discussed about the advantages of parabolic dish collectors with tracking in solar thermal power conversion, the concentration ratio can reach 1000 by minimizing the receiver size. Tian and Zhao et.al.[2] reviewed about present and proposed solar power plants, heat transfer fluids, categories of storage materials for sensible heat, latent heat, and chemical storages with heat transfer enhancement techniques. The effects of optical error, rim angle and heat loss coefficient were discussed by Huairui Li et al. [3], which relates the heat loss rate to the annual average solar radiation, for cavity receivers with and

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Nomenclature

A_{ref}	Area of the reflector(m^2)	β	Ratio of thickness of nano layer to radius of nano particle
$A_{Re\,ff}$	Effective area of the receiver(m^2)	U_{LF}	Heat loss factor
E_{xF}	Exergy factor	c_{pnf}	Specific heat capacity of nano fluid
E_S	Solar power on the reflector	$\dot{m}$	Mass flow rate of HTF
E_a	Energy focused on the receiver (kW)	Re	Reynolds number
E_R	Energy gained by the receiver through the HTFs (kW)	Nu	Nusselt number
$E_{xS\text{-}D}$	Exergy sun to dish	ϕ	Volume fraction of particle
E_{xR}	Exergy rate (kW)	c_{av}	Average specific heat capacity (J/kgK)
E_L	Total energy loss (kW)	T_{in}	Fluid inlet temperature
$h_{\exp}$	Convective heat transfer coefficient from experiment	T_{out}	Fluid outlet temperature
I	Solar Direct Normal Irradiation (DNI- W/m^2)	D_h	Hydraulic diameter
k_{eff}	Effective thermal conductivity of Nano fluid (W/mK)	T_{atm}	Atmospheric temperature
k_{Static}	Thermal conductivity of in static suspension (W/mK)	T_{avg}	Average wall temperature
$k_{Brownian}$	Thermal conductivity with Brownian motion (W/mK)	η_{ExR}	Receiver exergy efficiency
k_p	Thermal conductivity of nanoparticles(W/mK)	η_{EnR}	Receiver energy efficiency
k_b	Thermal conductivity of base fluid (W/mK)	μ_{nf}	Viscosity of the nano fluid
K_B	Boltzmann constant (1.381×10^{-23} J/K)	r_{nf}	Density of nano fluid

without window. In this work the preferred rim angle and the optical error of the parabolic dish reflector to achieve optimum intercept factor and absorptivity for the cavity receiver are discussed. The preferred rim angle for the cavity receiver without window should be more than 50° with less than 4m radius of optical error , whereas for the windowed one the recommended rim angle must be less than 50° and the optical error value may lie above 4 m radius.

Steinfeld and Schubnell [4] described a method named semi empirical approach to optimize the radius and the temperature ranges of the receiver for parabolic collectors. The absorption efficiencies are high when the temperature is below 700 K (the efficiency is 100% at 300 K and for 8 cm radius) for bigger radius of the absorber, which intercepts all the reflected solar radiations from the parabolic dish; whereas above 700 K, it reduces and keeps constant regardless the variation of the absorber radius, (the absorption efficiency reduces to 50% at 1700 K and 0% at 2019 K for the same 8 cm absorber radius), because bigger radius lead to significant increase in the radiative losses at higher temperatures. Mathew Neber et.al [5] experimented a point focusing dish collector for residential (small) scale applications to generate electricity with Brayton cycle by reaction bonded SiC material (with higher thermal conductivity and emissivity/ absorptivity) for the receiver with diameter of 72 mm and reflector of 17 square meters, which has been proved more suitable for smaller scale CSP systems to withstand the temperature of 1700 K with the generating output of 2.5 kW through higher concentration of 4175 suns (1000 W/m^2 of DNI = 1 sun). Isabel Roldan et al [6] made thermal analysis by CFD software FLUENT through 3D, RNG, K-ε turbulence model with geometries of square, cylindrical (tube), with compositions of five different refractories for several wall thickness of refractory, insulation and frame arrangement. The best geometry among them was cylindrical (tube) with baffle plated, which was made by refractory material composition of 53.43% of Al_2O_3, 39.6% of SiO_2, 1.1% Fe_2O_3, 1.6% of TiO_2 and 3.3% of CaO. The better thermal gradient between wall and heat transfer fluid was achieved for the refractory wall thickness of 15 cm and insulation thickness of 15 cm and frame thickness of 5 cm, with the maximum fluid temperature of 1350 K at the central section.

The research on directional characteristics of focal flux was carried out by Shuai Yong et al [7] through Monte-Carlo Ray-Tracing method coupled with the optical properties of the plano-convex quartz window. This analysis reveals, the efficiency of the quartz windowed cavity receiver is higher than the windowless one, when the reference temperature is higher than the critical temperature (800°C). The quartz window distributes the radiative flux uniformly throughout the cavity absorber and hence the temperature distribution on the receiver is also found uniform, which in turn reduces the losses of radia-

tion and wall emissivity resulting better thermal efficiency. Reddy et al. [8] developed a modified receiver model to achieve an average thermal efficiency of 74% for the flow rate of 250 liters per hour, which may suit for steam generation applications. The maximum energy and exergy efficiencies found for a cylindrically coiled tubular receiver with air as heat transfer fluid were 82% and 28% respectively based on the maximum gained thermal energy and exergy rates of 21.3 kW and 8.8 kW, respectively, by Jianqin Zhu et al.[9].

Xiang-Qi Wang et al. [10] made a review on the heat transfer characteristics of nano fluids by experimental studies and analytical models with more attention to thermal conductivity. The heat transfer performance of 80% was achieved for water based copper nano fluid with 10% volume fraction and 100% for oil based carbon nano tubes of 1% volume fraction. Applications of nano fluids in solar energy was reviewed by Omid Mahian et al.[11] through the results of experimental and numerical studies, about the enhancements of efficiency in the performance of solar energy systems, this review paper focuses on the improvements of collector efficiency based on increasing the particle size in nano meter range and selecting suitable volume fraction (the maximum efficiency may be at 1%) by experiments. The heat transfer enhancement in silicon carbide (SiC)/water nano fluid of 170 nm with 3.7% volume concentration was experimented by Wenhua Yu et al.[12]. The results on the convective heat transfer coefficient had increased in between 50 to 60% above the base fluid (water) for constant Reynolds number, regarding the merit parameter, 0.8 for silicon carbide (SiC)/water nano fluid and 0.6 for Al_2O_3 /water.

Said et al. [13] made a review about the increase of radiative properties and high absorption for more storage capacities at higher temperatures. The investigations discussed Nano particles of carbon nano horns, graphite and silver with base fluid like water, ethylene glycol, propylene glycol and therminol VP-1 in heat transfer applications. The review work also studied scattering of rays, radiative heat transfer and other above-mentioned properties of nano fluid which depend on size, shape structure and volume fractions with respect to the surfactant used. The study also explored that around 50 nm range particle size with volume fractions of 10^{-5} to 10^{-2} is more suitable for solar energy conversion applications. A volumetric receiver’s efficiency of more than 35% was obtained through the direct absorption, and thermal re-emission of carbon coated nano fluid with optimized optical thickness to enhance the radiative properties was discussed by Andrej Lenert and Evelyn Wang [14]. Elias et al. [15] experimented and proved the enhancements in thermal conductivity, overall heat transfer coefficient and heat transfer rate by using the nano fluid of boehimate alumina nano particles with ethylene glycol and water through different shapes (cylindrical ,brick, platelets and blades) and volume fractions. Also from the experimental results the cylindrical shaped nano particle with 1%volume fraction showed better overall heat transfer coefficient compared to other particle shapes.

The important conclusions from the results of the reviewed literatures clearly indicate that the overall performance of the collector system can be improved by minimizing the convective and radiative heat losses through proper selection of geometry, heat transfer fluid with optimum heat transfer properties (volume fraction and particle size of nano fluid) and material for the receiver. In this regard a cavity type receiver was designed and fabricated using aluminium material and SiC+Water nano fluid was selected to study the performance of the CSP system. In this work the energy and exergy efficiencies with exergy factor of the cavity receiver have been compared for two heat transfer fluids, Water and SiC + water nano fluid.

Experimental method

Experimental setup

The experiment has been carried out between 12:30 h and 14:30 h, at Melmaruvathur (12°30' N latitude and 79°30' E longitude) near the city of Chennai in India. The point focusing reflector made by glass mirror with reflectivity of 93% and reflector area of 12 square meters was fabricated with the rim angle of 50° for the focal length of 2.16 m.The cavity receiver of no window type was selected to achieve better interception factor and performance, where the working temperature is below 800°C. The length to diameter ratio of 1.5 (L/D = 1.5) for the receiver with the concentration ratio of 381.97 was designed and fabricated with aluminium material. The bigger diameter of 16cm for the cavity has been selected to absorb all the reflected solar radiations, where the radiative losses (below (700 K) are very little. The receiver with inner and outer diameters of 160 mm and 200 mm for the length and cavity depth of 300 mm and150 mm has been given to effectively absorb the Direct Normal Irradiations (DNI). The helically coiled copper tube with 12 number of turns, dimensions of 10 mm inner and 12 mm outer diameter is arranged between the inner and outer walls up to the length of 3/4 th of the receiver. The performance of the cavity receiver has been studied for enhancements in conduction, convection and radiation modes of heat transfers with two heat transfer fluids; the entire external wall surface has been insulated with thickness of 50 ± 0.5 mm asbestos material.

The components of entire experimental setup with flow paths and data acquisition are shown in the schematic diagram. The DNI from the sun was measured by a solarimeter, accuracy of ±1 W/m^2 with least count of

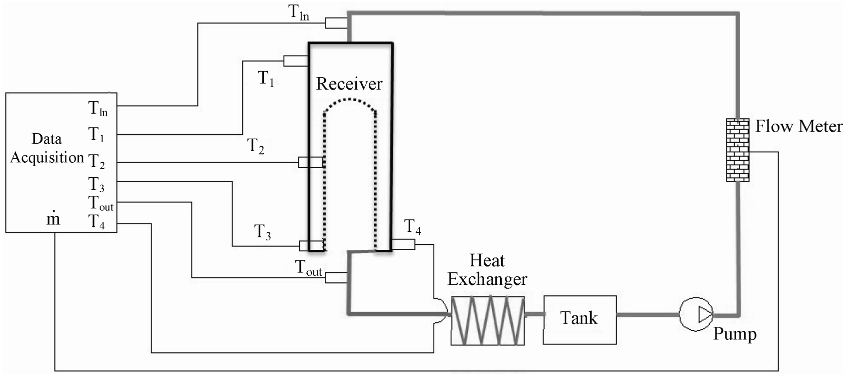

Fig. 1 Schematic diagram of experimental setup

1 W/m^2 and working ranges of 0-2000 W/m^2, respectively. The temperature measurements were monitored and recorded for every five minutes by K-type thermocouples in different locations on the receiver as shown in the diagram, the thermocouples T_1, T_2, T_3 and T_4 measure the temperatures of the top, middle, and the bottom wall temperatures of the cavity receiver, whereas the inlet and outlet temperatures of the fluids (water or SiC+water nano fluid) are measured by the thermocouples Tin and Tout which are mounted on the top and bottom of the fluid paths, respectively. The data acquisition is accomplished by the National Instruments data acquisition system with the support of Lab VIEW software. The heat transfer fluid was pumped into the receiver from the top by a booster pump of nominal flow rate of 1.8 lpm and maximum inlet pressure of 60 PSI and the flow rates were measured through a Rota meter of range 0-2 lpm. The estimated uncertainties through propagation of error method for energy and exergy rates with respect to flow rates and temperatures are ±1% and 0.2°C respectively. The energy and exergy analysis have been done for the steady solar radiations time period of 12.30 to 14.30 h, from the best acquired data of 14 days during the month of June, in the year of 2016.

Nano fluid characterization

Based on the literature survey, the particle size, volume fraction and the heat transfer properties like viscosity, thermal conductivity, and convective heat transfer coefficient have been condidered in this work to enhance the energy and exergy efficiencies of the collector system. The particle size and distribution in the suspension with surfactant used are the major factors in the agglomeration of particles. The selected particle size and volume fraction based on the literatures were 50 nm and 1% from the effective values of 20−50 nm and 1%−4% [11,12] in particle size and volume fraction respectively. This work aims to study the conductive, convective and radiative modes of heat transfers in the cavity receiver by heat transfer fluids (Water, SiC+Water) with respect to the geometry.

$$\mu_{nf} = \mu_w + (1 + 0.25\phi) \quad (1)$$

The viscosity of the nano fluid (μ_{nf}) which causes the pressure drop and thus requires more pumping power [11] was carefully estimated to be low by selecting the SiC volume fraction of 1% and particle size of 50 nm through dispersant (surfactant) of Triton X -100. with weight percentage of 1(1%) [16,17]. Figs. 2 and 3 show the SEM image with quantitative results of SiC particles, respectively.

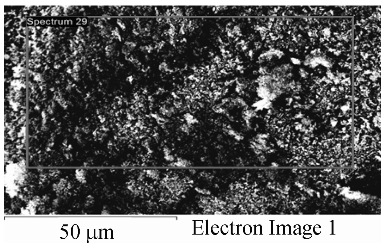

Fig. 2 SEM image of SiC Nano particles

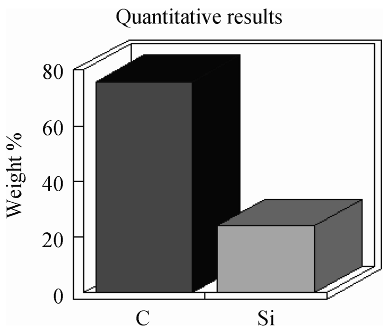

Fig. 3 Quantitative results of C and Si

Thermal conductivity of nano fluids from the Koo and Kleinstreuer correlation

Generally the thermal conductivity of nano fluids are determined by experiments or by simulation models and also from correlations, here it is calculated from selected

semi empirical correlations, actually thermal conductivity of nano fluid is based on the thermal conductivities of particle and base fluid with respect to the other considerations like particle size , volume fraction, particle dispersion and stability of the fluid considering the surfactant used, temperature applied, interaction between particles, convective heat transfer coefficient from surrounding particles to base fluid due to Brownian movement, interfacial thermal layer, Reynold's number, Prandtl number and Raleigh's scattering. Empirical correlations of Maxwell, Bruggman, Prasher, Koo and Kleinstruer and simulations of Bhattacharya and Xuan-Yao studied based on the present needed parameters [10,11 &18].

$$k_{eff} = k_{static} + k_{Brownian} \tag{2}$$

$$k_{eff} = \frac{k_p + 2k_b + 2\left(k_p - k_b\right)\phi}{k_p + 2k_b - \left(k_p - k_b\right)\varphi} + 5\times10^4 \beta\varphi\rho_\varphi \frac{1}{k_b} C_p \sqrt{\frac{k_\beta T}{\rho_p d}} f\left(T,\varphi\right) \tag{3}$$

The effective thermal conductivity (k_{eff}) of the nano fluid is the sum of static thermal conductivity (k_{static}) of nano fluid, which basically depends on the thermal conductivity of the base fluid (k_b) and the effect of Brownian movement ($k_{Brownian}$) [17]. The effective thermal conductivity and the ratio of (k_{eff} / k_b) have been calculated as 0.8001154 W/mK and 1.1759 respectively, through the correlation by Koo and Kleinstreuer, which considers both Maxwell correlation and Brownian motion with the effects of volume fraction, particle size, and temperature.

$$\rho_{nf} = \rho_p\varphi + \left(1-\varphi\right)\rho_w \tag{4}$$

$$C_{pnf} = \frac{\left(1-\varphi\right)\left(\rho C_p\right)_w + \varphi\left(\rho C_p\right)_p}{\rho_{nf}} \tag{5}$$

The value of β is assumed as 0.1, which is the ratio of thickness of nano layer to radius of nano particle. Theoretically the determined values of specific heat capacity (C_{pnf}) and density (ρ_{nf}) of nano fluid were also verified through energy balance from experiments. The density and specific heat capacity of nanofluid were determined through the above correlations based on the specific heat capacities $(C_p)_p$, densities (r_p) with respect to the volume fraction (ϕ) of the nano particle and the specific heat capacities$(C_p)_w$, densities (ρ_w) of the base fluid (water) respectively [12] .

Convective heat transfer in nano fluid through experimental calculations

In this work the values of convective heat transfer coefficient, Reynolds numbers (Re) and Nusselt numbers (*Nu*) are [12, 19] determined through experimental data of average receiver temperature, mass flow rate for water and SiC+water nano fluid temperatures.

$$Nu = \frac{h_{\exp} D_h}{k_{eff}} \tag{6}$$

Where $h_{\exp}$ is the convective heat transfer coefficient of the heat transfer fluids (water and nano fluid), D_h is the hydraulic diameter, K_{eff} is the thermal conductivity of the nano fluid. The determined values of Nusselt numbers for the flow rates of 0.2 lpm to 0.6 lpm for both the heat transfer fluids have been studied, the maximum Nusselt number value for the SiC+Water nano fluid is 13.77%, higher than that of water at the flow rate of 0.5 lpm.

Energy and Exergy Analysis

The thermal performance of the cavity receiver system has been studied through experimental data by means of applying energy and exergy analysis (first and second law of thermodynamics) for two heat transfer fluids. This work focuses on enhancing the thermal energy efficiency and the exergy factor (maximum energy quality) of the collector system. The temperature difference between wall and HTFs has impact on exergy factor [9], hence the geometry of cavity receiver and heat transfer fluids (water, SiC+ water nano) are selected to enhance the conductive, convective and radiative modes of heat transfer. The conclusion from literatures reveals that importance should be given to the selection of solar collector system to improve the exergy efficiency, hence rather than the flat plate collectors, other collectors (glass widow covered or coated cavity receivers with heating device called reflectors) are preferred to avoid exergy destruction [20]. The energy and exergy analyses give an understanding about the relationship between the system performance and technical characteristics like reliability, sustainability, availability, maintenance and environmental impacts [21]. In this experimental work a dish reflector and cavity receiver have been taken up to analyze the energy and exergy efficiencies, to maintain the system in constant heat flux.

The performance of the cavity solar receiver has been characterized by analyzing the energy and exergy parameters through the solar dish reflector of 12 m^2 which focuses the DNI of the sun by a manually operated tracking system. The point focusing collector is closely monitored for uniform and constant heat flux on the cavity absorber during the experiment period of 14 days with the two different heat transfer fluids (water, SiC+ water nano), separately for the flow rates of 0.2 lpm to 0.6 lpm with an interval of 0.1 lpm.

Energy analysis

The absorber of the cavity receiver receives entire energy from the direct normal irradiations (DNI) through the focused radiations by the dish reflector from the sun. The solar power on the reflector as [9]:

$$E_s = A_{ref} I \tag{7}$$

Where A_{ref} is the area of the reflector and I denotes the direct beam or direct normal irradiation. The energy focused on the cavity receiver is based on the optical efficiency (η_{op}), which is based on the optical properties and the concentration ratio (reflector area /receiver).

$$E_a = \eta_{op} E_s = \left(T_{out} - T_{in}\right) \quad (8)$$

The rate of power or the power received by the receiver from the two different heat transfer fluids (water, SiC+ water nano) during the experiments

$$E_R = \dot{m} c_{av} \left(T_{out} - T_{in}\right) \quad (9)$$

The mass flow rates ($\dot{m}$) for the average specific (c_{av}) heat of the heat transfer fluids are based on the average temperature of the receiver. The energy conservation or the gained energy is the difference between focused DNI (heat flux) on the absorber (E_a) and the heat losses (E_L) from the receiver. The receiver energy gain (E_R), can be expressed as

$$E_R = E_a - E_L \quad (10)$$

$$E_L = U_L A_{\mathrm{Re}\,ff} \left(T_{avg} - T_{atm}\right) \quad (11)$$

The energy balance for the receiver based on the absorber and heat transfer fluid is considered by the overall loss coefficient or heat loss factor (U_{LF})

$$U_{LF} = U_L A_{\mathrm{Re}\,ff} \quad (12)$$

$$\dot{m} c_{av} \left(T_{out} - T_{in}\right) = \eta_{op} A_{ref} I - U_{LF} \left(T_{avg} - T_{atm}\right) \quad (13)$$

Thermal efficiency of the receiver is the ratio of heat (power) gained by the receiver to the concentrated heat flux (power) on the cavity area of the receiver by the dish reflector

$$\eta_{thR} = \eta_{EnR} = \frac{E_R}{E_a} = \frac{\dot{m} c_{av} \left(T_{out} - T_{in}\right)}{\eta_{op} A_{ref} I} \quad (14)$$

Fig. 4 Solar dish reflector and receiver

Exergy analysis

The solar exergy rate by the sun to the dish reflector then to the receiver is expressed as [9]

$$E_{xS-D} = \eta_{op} \left[A_{ref} \left(1 + \frac{1}{3} \left(\frac{T_{atm}}{T_s} \right)^4 - \frac{4}{3} \left(\frac{T_{atm}}{T_s} \right) \right) \right] \quad (15)$$

The exergy rate, which is the quality of useful energy to the HTFs by the receiver with respect to the surroundings, is expressed by the following relationship

$$E_{xR} = \dot{m} c_{av} \left[\left(T_{out} - T_{in}\right) - T_{atm} \ln\left(\frac{T_{out}}{T_{in}} \right) \right] \quad (16)$$

The energy absorbing capacity or the energy conversion ability of the thermal system is termed as exergy efficiency of the cavity receiver, which is expressed as the ratio of output exergy from the receiver to the exergy supplied to the receiver through the dish reflector.

$$\eta_{E_{xR}} = \frac{E_{xR}}{E_{xS-D}} = \frac{\dot{m} c_{av} \left[\left(T_{out} - T_{in}\right) - T_{atm} \ln\left(\frac{T_{out}}{T_{in}} \right) \right]}{\eta_{op} \left[A_{ref} \left(1 + \frac{1}{3} \left(\frac{T_{atm}}{T_s} \right)^4 - \frac{4}{3} \left(\frac{T_{atm}}{T_s} \right) \right) \right]} \quad (17)$$

The exergy factor is the ratio of exergy rate to energy rate of the cavity receiver.

$$E_{xF} = \frac{E_{xR}}{E_R} = \frac{\dot{m} c_{av} \left[\left(T_{out} - T_{in}\right) - T_{atm} \ln\left(\frac{T_{out}}{T_{in}} \right) \right]}{\dot{m} c_{av} \left(T_{out} - T_{in}\right)} \quad (18)$$

Results and discussion

The experiment was conducted for different flow rates with water and Sic water nano fluid separately for different days but at nearly constant atmospheric conditions with the average DNI (around 810 W/m^2) and wall temperatures to study the energy and exergy efficiencies of the concentrated solar energy collector (dish reflector and receiver) system.

The flow diagram shows the thermal energy (energy) and exergy efficiencies at 0.5 lpm while the water and the nano fluid were used separately as heat transfer fluids in the receiver while the energy and exergy received by the dish concentrator (dish reflector) are 9.62418 kW and 5.04653 kW with the loss of 3.11342 kW and 1.63256 kW, respectively. The energy and exergy of the solar receiver were 6.51076 kW and 3.41397 kW, respectively, whereas the energy and exergy carried by the heat transfer fluid water were 1.92842 kW and 1.25297 kW, respectively. While considering the nano fluid, the energy and exergy were 2.16622 kW and 2.01224 kW, respectively, it shows that the energy and the exergy carried by the nano fluid are 0.2378 kW and 0.7593 kW higher than that of water. The respective difference in the loss of energy and exergy in the receiver for water and the nano fluid are 0.2378 kW and 0.7593 kW, which is equal to its higher gained value , it shows that the losses have been minimized while the nano fluid is in use; and also from the flow diagram it is found clearly that the energy and the exergy for the water and nano fluid were well balanced with the gain and the losses of the solar collector (reflector and receiver) system.

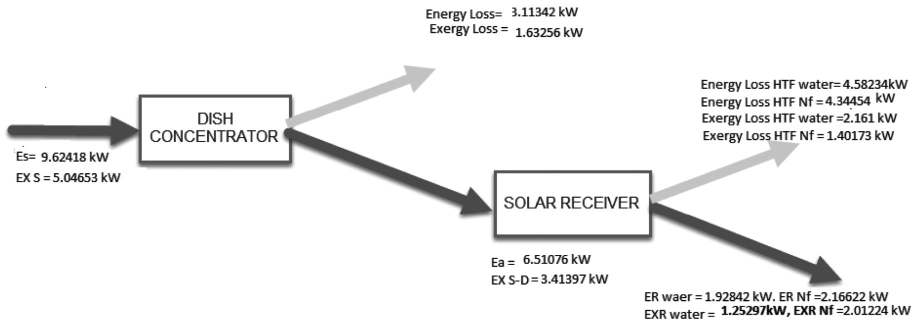

Fig. 5 Flow diagram of energy & exergy for the dish collector experiment during afternoon condition

Fig. 6 shows the average values of DNI for every 15 minutes and corresponding wall temperatures to study the energy and exergy performances of the receiver for two hours during the afternoon time, in between 12.30 h to 14.30 h.

The overall heat loss factor for the low temperature small scale range (below 700 K) concentrated solar power receiver has been plotted (Fig. 7) with respect to the local time. The experimental results show high convective (4.30 kW) and very low (0.085 kW) radiative losses and also with the overall loss coefficient or heat loss factor (ULF) of 0.646 to 0.242 during 12:45 h and at 14:30 h respectively.

Fig. 8 shows the maximum energy efficiency value of 32.91% for nano fluid and 29.94% for water based on wall temperatures at the flow rate of 0.5lpm; this higher value of energy efficiency for the nano fluid is due to enhanced thermal conductivity (K_{eff} = 0.8001154 W/mK) and convective heat transfer coefficient (h_{exp} = 0.688 W/m^{2}K) of nano fluid as compared to water (K = 0.6808W/mK), h_{exp} = 0.331 W/m^{2}K). While considering the energy efficiency of nano fluid, the variations (32.91%−32.77%) are uniform after the peak value as compared to water (29.14%−26.17%), which drops suddenly. This is due to the energy losses from the receiver to the atmosphere while nano fluid (4.34454 kW) and water (4.58234 kW) in use, it is also based on the energy conversion efficiencies of the fluids (water 1.92842 kW and nano fluid 2.16622 kW), it is clearly indicated in the flow diagram.

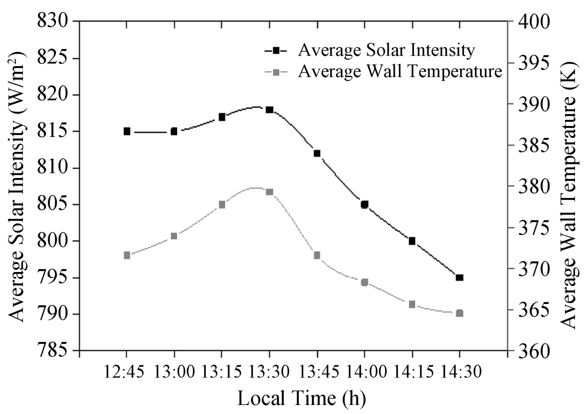

Fig. 6 Variation of average DNI and average wall temperatures with local time

The exergy efficiencies at the flow rate of 0.5 lpm with maximum of 39.83% and 24.82% for nano fluid and water respectively, it is because of the average quantities of exergy losses of nano fluid (1.40173 kW) is less than that of water (2.161 kW). The value of exergy efficiencies

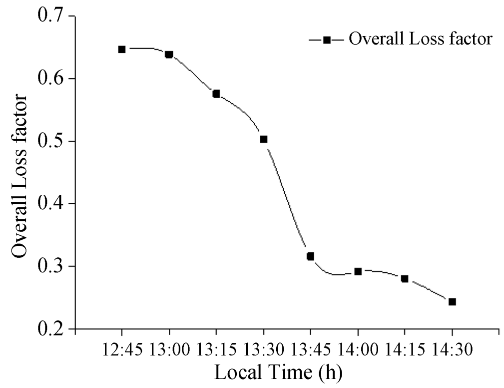

Fig. 7 Variation of overall heat loss factor from the receiver with local time

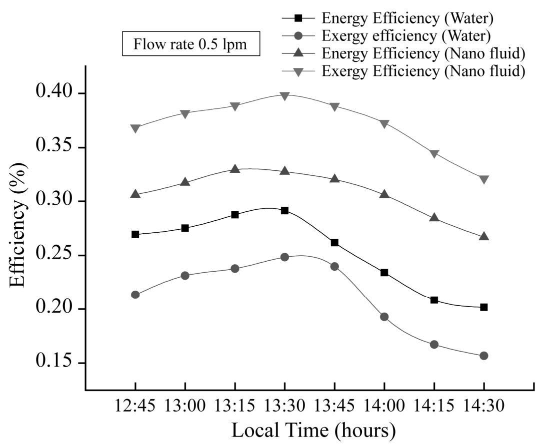

Fig. 8 Variation of energy and exergy efficiencies of water and nano fluid at 0.5 lpm with local time

drop uniformly for the nano fluid, whereas suddenly for water, because of the increased thermal conductivity and Nusselt number of SiC/water, which helps the receiver sustain uniform temperature difference between the wall and the HTF, which in turn enhance the exergy efficiency of nano fluid by 37.68% than water at the flow rate of 0.5 lpm. At the local time of 13:30 h where the intensity of solar irradiation and the absorber temperature are the maximum (Fig.6), the exergy efficiencies of both fluids are also found maximum, it shows that the exergy efficiency is based on the higher inlet temperature and temperature difference of receiver [9] with the atmosphere.

Fig. 9 shows at the flow rate of 0.6lpm the energy efficiency of water varies uniformly and drops from the maximum efficiency of 29.76% at 13:15 h, but the nano fluid energy efficiency varies non-uniformly with up and down and reaches the maximum efficiency of 31.39% at 13:30 h. The exergy efficiency drops for both HTFs, but it is clear from the plot that the value of exergy efficiencies varies non-uniformly for nano fluid than water and is also lower compare to the value of 0.5 lpm flow rates for the nano fluid. The maximum exergy efficiency at 0.6 lpm is 21.23% (13.15 h) and 33.79% (13:45 h) for water and nano fluid, respectively. The energy and exergy efficiencies for the nano fluid at the flow rate of 0.6 lpm is fluctuating and dropping lower than at the flow rate of 0.5 lpm, which may be caused by the increase of laminar sublayer by the enhanced values of density (985.96 kg/m^3 at 1200 C) and viscosity (0.0006022 kg/ms) of the nano fluid with 1% volume fraction. Even though the improved properties of nano fluid like thermal conductivity and density reduce the laminar sub-layer by thermal diffusion, the enhanced viscosity may increase the laminar sub-layer of the boundary, which will widen the temperature difference (decrease in thermal conductivity) between the wall and the fluid. The same trend has been discussed by Wenhua Yu et al[12] in the heat transfer experiments conducted on water based SiC nano fluid. This problem may be overcome by optimizing the particle size, volume concentration for higher velocities to reduce the viscosity, which may decrease (increase the thermal conductivity) the laminar sub-layer.

Fig.10 shows throughout the experiment period for flow rates of 0.2 lpm to 0. 6 lpm the thermal efficiency (energy) of SiC/Water nano fluid is higher than that of water, with exception only at the flow rate of 0.2 lpm. The values of exergy efficiency of nano fluid are higher than that of water for the flow rates from 0.2 to 0.6 lpm. At 0.5 lpm the maximum value of exergy efficiencies for nano fluid and water are 39.83% and 24.82%, respectively, which shows the enhanced energy (exergy) conversion ability (enhanced heat transfer properties) of the nano fluid is higher than that of the base fluid water.

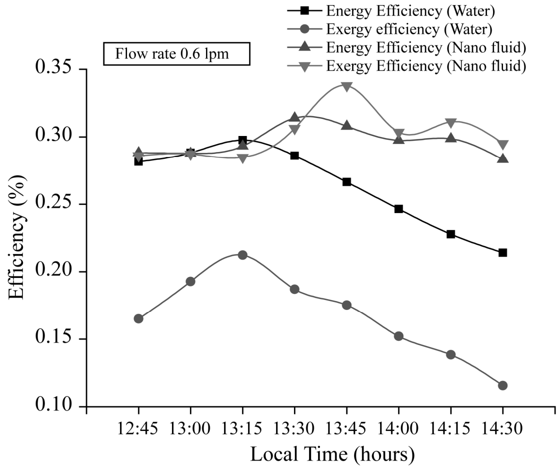

Fig. 9 Variation of energy & exergy efficiencies at the flow rate of 0.6 lpm with local time

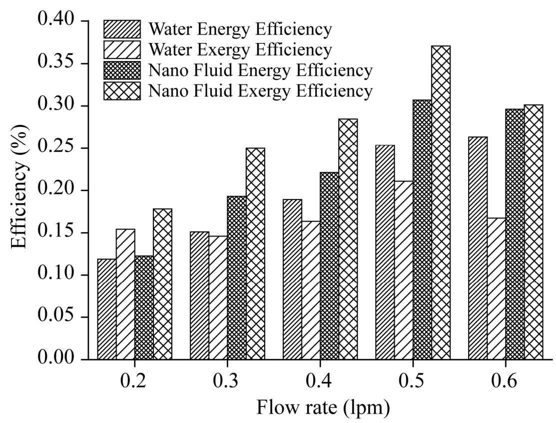

Fig. 10 Comparisons of energy and exergy efficiencies for water and nano fluid based on flow rates

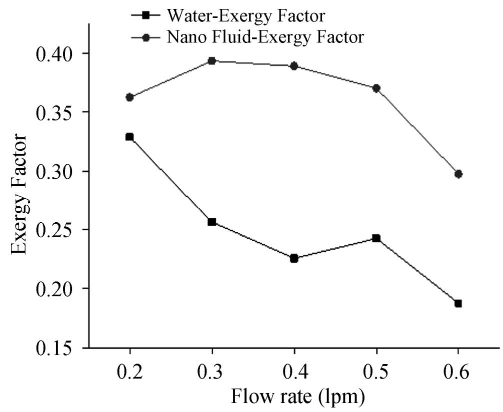

Fig. 11 Comparison of exergy factors of water and nano fluid for the flow rates from 0.2 to 0.6 lpm.

The ratio of energy rate to exergy rate (exergy factor) for the receiver is shown in Fig.11, with the maximum values of 0.3932 (0.3 lpm) and 0.3286 (0.2 lpm) for the

nano fluid and the base fluid water, respectively. The reason for the exergy factor difference between the two HTFs are clearly indicated in the flow diagram (Fig. 5), which shows that the average exergy loss and exergy rates of the nano fluid are 35.16% lower and 23.88% higher than that of water. Also from Fig. 12, the exergy factors for the nano fluid for different flow rates are higher than that of water. It is advisable that optimizing the particle size (to enhance specific heat capacity) and volume fraction (to enhance density) enhances the energy and exergy efficiencies at 0.6 lpm, which in turn will improve the exergy factor.

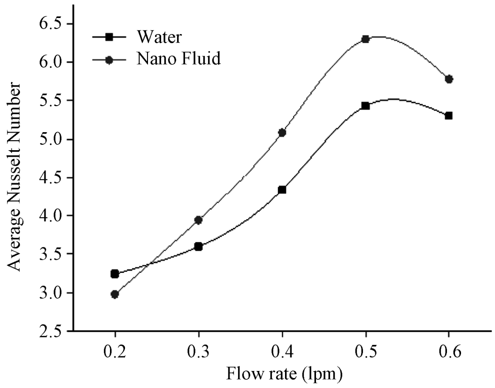

Fig. 12 Variation of average Nusselt number with respect to flow rates for water and nano fluid

Fig. 12 shows the variations of average Nusselt number with respect to flow rates. At the flow rate of 0.2 lpm the average Nusselt number for water is higher than that of nano fluid, thereafter 0.2 lpm, the average Nusselt number values for nano fluid is higher than water for all other flow rates. The average Nusselt number is higher at the flow rate of 0.5 lpm for the nano fluid than that of water, also after the flow rate of 0.5 lpm the Nusselt number value starts to decrease. It is clear from Fig. 12 that the maximum average Nusselt number values are 6.299 and 5.431 for nano fluid and water, respectively. It indicates that the convective heat transfer coefficient gradually increases up to 0.5 lpm and thereafter it starts to decrease. This may lead to decrease in energy and exergy efficiencies of nano fluid beyond 0.5 lpm.

Conclusions

In this study, concentrated solar dish reflector and cavity receiver collector system is fabricated and experimented to find the energy efficiency, exergy efficiency, and exergy factor for the same solar intensity with water and SiC +water. The following conclusions can be drawn:

The energy and exergy efficiencies of the solar receiver with water as heat transfer fluid vary with flow rate for the same solar intensity. The energy efficiency increases from 12.74 to 29.14% when the water flow rate increases from 0.2 to 0.6 lpm. For the same solar intensity, the exergy efficiency varies from 16.61 to 24.82% when water flow rate increases from 0.2 to 0.5 lpm. The exergy efficiency (21.23%) starts to decrease at water flow rate of 0.6 lpm. Compared with energy efficiencies, the exergy efficiencies are lower for water except at 0.2 lpm.

The energy efficiency increases from 12.52 to 32.91% when the nano fluid flow rate increases from 0.2 to 0.5 lpm. For the same solar intensity, the exergy efficiency varies from 18.33 to 39.83% for increasing nano fluid flow rate from 0.2 to 0.5 lpm. The energy and exergy efficiencies (31.39% & 33.79%) start to decrease at 0.6 lpm nano fluid flow rate. Compared with energy efficiency, the exergy efficiency is high for all the flow rates of nano fluid.

The maximum energy efficiencies of 29.14% and 32.91% were obtained at the flow rate of 0.5 lpm for water and nano fluid, respectively. The maximum exergy efficiencies of 24.82% and 39.83% were obtained at the flow rate of 0.5 lpm for water and nano fluid, respectively. The enhanced energy and exergy efficiencies of 12.94% and 60.48% have been achieved by SiC+water nano fluid as heat transfer fluid than that of water at the flow rate of 0.5 lpm.

The ratio of energy rate to exergy rate (exergy factor) of the receiver is better (maximum 0.3932 & average 0.363) for the nano fluid than water (maximum 0.3286 & average 0.2480) for all the flow rates.

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